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SUBJECT: Propagation Characteristics of Apollo 8 L.P.O. Solutions Obtained from the Osculating Lunar Elements Program - Case 310

DATE: September 30, 1969

FROM: M. V. Bullock
A. J. Ferrari

ABSTRACT

An analysis of state vector solutions resulting from the Osculating Lunar Elements Program (O.L.E.P.) processing of Apollo 8 tracking data is performed. The solutions are investigated for consistency by comparing successive two pass O.L.E.P. regressions with two pass propagated O.L.E.P. states. Local vertical dispersions and orbital element differences are considered. O.L.E.P. solutions are also compared with single pass R2 lunar gravity field solutions, in a local vertical coordinate system, to study similarities with results from conventional techniques. O.L.E.P. solutions are found to be self-consistent and to compare reasonably with conventional results.

(NASA-CR-107372) PROPAGATION CHARACTERISTICS OF APOLLO 8 LPO SOLUTIONS OBTAINED FROM THE OSCULATING LUNAR ELEMENTS PROGRAM (Bellcomm, Inc.) 20 p

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MEMORANDUM FOR FILE

INTRODUCTION

In the analysis of Apollo 8 tracking data using the Osculating Lunar Elements Program (O.L.E.P.),* the Doppler errors grew by about a factor of five from each two pass regression zone to each two pass propagation zone. A technique which can be used to investigate the particular characteristics of these errors is to compare the vehicle state in successive regression zones to a state that has been propagated forward from earlier regression zones. The basic assumption in this analysis is that the regression zone, or local solution, is more truly representative of the actual osculating state of the vehicle. It is further assumed that if the Doppler errors can be minimized, then the associated navigation errors will also be minimized.

The actual propagation analysis consists of two parts. The first of these is a comparison of two pass propagated O.L.E.P. solutions. The second is a comparison of two single pass R2 lunar gravity field solutions with two pass propagated O.L.E.P. solutions. The O.L.E.P. versus O.L.E.P. comparisons demonstrate the self-consistency of O.L.E.P. solutions, whereas the R2 versus O.L.E.P. comparisons demonstrate how O.L.E.P. solutions compare to single pass regressions using conventional techniques.

The comparisons are made in a local vertical system (U-radial, V-along track, W-cross track) generated from the instantaneous rectangular selenographic vehicle state. Differences in the osculating selenographic Kepler elements are also considered.

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*Bullock, M. V. and Ferrari, A. J., "An Analysis of Apollo 8 Tracking Data Utilizing the Osculating Lunar Elements Program", Bellcomm TM-69-2014-8, June 30, 1969, Case 310.

COMPARISONS OF O.L.E.P. LOCAL AND O.L.E.P. PROPAGATED SOLUTIONS

Two types of consistency comparisons were made using O.L.E.P. two pass solutions. The first of these compares the second pass of a regression zone and the adjacent propagated pass to a two pass local solution (e.g., $4,\hat{5}$ versus 4,5).* The second compares two propagated passes with the respective two pass local solution (e.g., $\hat{5},\hat{6}$ versus 5,6). In order to simplify matters, the former comparison will be referred to as Type I and the latter Type II. A numbering scheme has been adopted to facilitate the identification of both the Type I and Type II consistency comparisons. The table below lists the comparisons made and the associated numerical designators.

No.	Type I
1	$4, \hat{5}$ vs. 4, 5
2	$5, \hat{6}$ vs. 5, 6
3	$6, \hat{7}$ vs. 6, 7
4	$7, \hat{8}$ vs. 7, 8
5	$8, \hat{9}$ vs. 8, 9
6	$9,\hat{10}$ vs. 9,10

TABLE I

No.	Type II
1	$\hat{5}, \hat{6}$ vs. 5, 6
2	$\hat{6}, \hat{7}$ vs. 6, 7
3	$\hat{7}, \hat{8}$ vs. 7, 8
4	$\hat{8}, \hat{9}$ vs. 8, 9
5	$\hat{9},\hat{10}$ vs. 9,10

TABLE II

It should be noted that these numerical designators correlate with the indicators appearing on Figures 1a, 1b, 2a, 2b, 3a, and 3b. In comparisons of O.L.E.P. versus O.L.E.P. solutions the occultation zone has not been removed from the two passes.

Type I Comparisons

The local vertical deviations in position and velocity for all Type I comparisons are shown in Figures 1a and 1b respectively. The smallest deviations obtained were in the

*Hat (^) indicates extrapolated solution.

radial (U) component (δU_{max} = +450' to -300'). The magnitudes of these deviations reflect a consistency in the semi-major axes and eccentricities of the O.L.E.P. solutions. All of the down range (V) components have similar growth trends (δV_{max} = -3900'). These errors indicate mean anomaly and mean motion dispersions among the O.L.E.P. solutions. The cross track (W) components exhibit the largest errors and the most functionally inconsistent results. Two of the cases considered (5,6 vs. 5,6 and 7,$\hat{8}$ vs. 7,8) resulted in cross track deviations δW_{max} = ±10,000'. The rest of the cases had deviations of about δW_{max} = ±5000'. These errors imply variations in either the ascending node or the inclination of the O.L.E.P. solutions. The fact that the cross track deviations are the largest could perhaps be attributed to the relative insensitivity of the Doppler data type to the out-of-plane orbital elements (Ω, i).

<u>Type II Comparisons</u>

The local vertical deviations in position and velocity for Type II comparisons are shown in Figures 2a and 2b respectively. The errors associated with the Type II comparisons are functionally similar to the Type I deviations in the U and V components. Again the smallest error is in the radial component (δU_{max} = +1000' to -350') but about twice the Type I errors. The down range errors (V) have grown by a factor of about 2.5 (δV_{max} = -9000'). These errors are reflecting larger mean anomaly and mean motion dispersions in the Type II comparisons. The cross track errors have now become consistent in their phase relationship. With the exception of one comparison ($\hat{8}$, $\hat{9}$ vs. 8, 9; δW_{max} = ±10,000'), the out-of-plane deviations are very similar, with a maximum error of δW_{max} = ±6000'.

<u>COMPARISONS OF R2 LOCAL AND O.L.E.P. PROPAGATED SOLUTIONS</u>

The comparisons of R2 local and O.L.E.P. solutions, shown in Figures 3a and 3b, were made on a Type II basis (two single pass R2 solutions versus two pass propagated O.L.E.P. solution). The designators introduced in Table II for Type II comparisons will also be used here. In all cases the O.L.E.P. values were subtracted from the R2 values.

The radial component exhibits the smallest and most consistent deviations (δU_{max} = -2000'). These results indicate that a strong, bounded semi-major axis is obtained in O.L.E.P. solutions. The two pass (O.L.E.P.) semi-major axis is regularly smaller than the one pass (R2) value, a fact which is demonstrated by the δU curves being entirely below the X-axis. The down range dispersions (δV_{max} = +1000' to -6000') probably reflect the poor period information present in the two single pass R2 solutions. The cross track deviations are again larger than the in-plane deviations (δW_{max} = ±6000'). The results show the out-of-plane inconsistencies between one and two pass solutions.

ERROR TRENDS IN APOLLO 8 KEPLER SOLUTIONS

A Type II comparison was made of the orbital elements that resulted from O.L.E.P. processing of Apollo 8 tracking data. The results are presented below. Table II designators are used, and the average error for each element is shown.

Semi-major Axis: a

δa_1 = -136' $\quad |\overline{\delta a}|$ = 270'

δa_2 = -319'

δa_3 = -344'

δa_4 = -301'

δa_5 = -249'

Eccentricity: e

$\delta e_1 = -.2612 \times 10^{-4}$ $\quad |\overline{\delta e}| = .2383 \times 10^{-4}$

$\delta e_2 = -.1448 \times 10^{-4}$

$\delta e_3 = -.0341 \times 10^{-4}$

$\delta e_4 = -.2553 \times 10^{-4}$

$\delta e_5 = -.4961 \times 10^{-4}$

Inclination: i

$\delta i_1 = 0°.0217$ $\qquad \overline{\delta i} = 0°.028$

$\delta i_2 = 0°.0171$

$\delta i_3 = 0°.0269$

$\delta i_4 = 0°.0563$

$\delta i_5 = 0°.0194$

Longitude of Ascending Node: Ω

$\delta\Omega_1 = 0°.2905$ $\qquad \overline{\delta\Omega} = 0°.2781$

$\delta\Omega_2 = 0°.2269$

$\delta\Omega_3 = 0°.2340$

$\delta\Omega_4 = 0°.4148$

$\delta\Omega_5 = 0°.2242$

Modified Anomaly: $m = M + \omega$

$\delta m_1 = 0°.2873$ $\qquad \overline{\delta m} = 0°.2818$

$\delta m_2 = 0°.2290$

$\delta m_3 = 0°.2426$

$\delta m_4 = 0°.4190$

$\delta m_5 = 0°.2312$

In each case the solution orbital elements from a two pass regression zone were propagated forward to the beginning of the next pass and compared with a local solution at the epoch. The consistency of O.L.E.P. solutions is demonstrated by the fact that all of the offsets for any given element are in the same direction and are of the same order of magnitude. It would be possible to utilize the repeatability of the errors in a correction scheme by removing the mean error from a set of solution orbital elements before using them for propagation.

The Type II local vertical deviations discussed in Section II can be correlated with these orbital element offsets. Cross track deviations are the result of errors in the inclination and the longitude of the ascending node, the angles that determine the plane of the orbit. Errors in the modified anomaly give down range deviations, and radial dispersions are attributable to errors in the semi-major axis.

SUMMARY AND CONCLUSIONS

Characteristics of Apollo 8 state vector solutions from O.L.E.P. have been analyzed by comparisons of successive O.L.E.P. solutions and of O.L.E.P. and R2 lunar gravity field solutions. The results of the O.L.E.P. versus O.L.E.P. comparisons demonstrate the consistency of O.L.E.P. solutions. Errors in local vertical coordinates and in orbital elements have been investigated and have been seen to be complimentary. Differences in the inclination or the longitude of the ascending node can be correlated with cross track errors. Modified anomaly or mean motion differences manifest themselves in down range errors. Radial dispersions are directly relatable to semi-major axis offsets. The R2 versus O.L.E.P. results indicate that O.L.E.P. gives solutions of reasonable magnitude in comparison with conventional orbit determination processing solutions.

ACKNOWLEDGEMENT

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Attachments

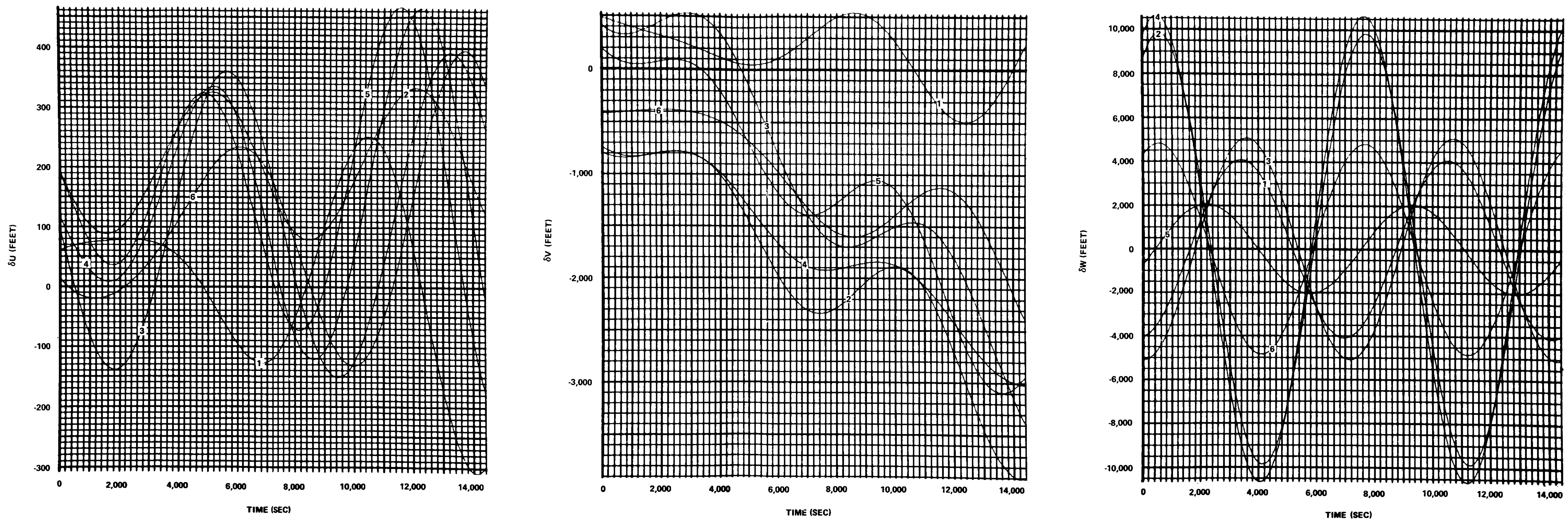

FIGURE 1a - TYPE I COMPARISONS (δU, δV, δW POSITIONS)

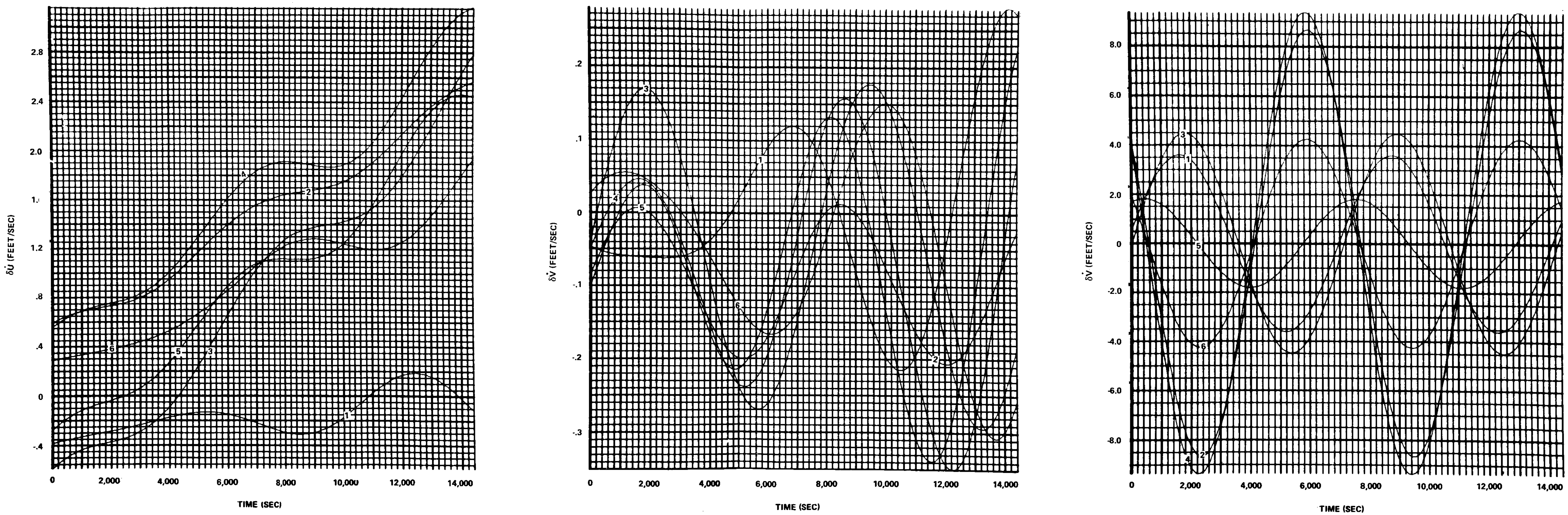

FIGURE 1b- TYPE I COMPARISONS ($\delta\dot{U}$, $\delta\dot{V}$, $\delta\dot{W}$ VELOCITIES)

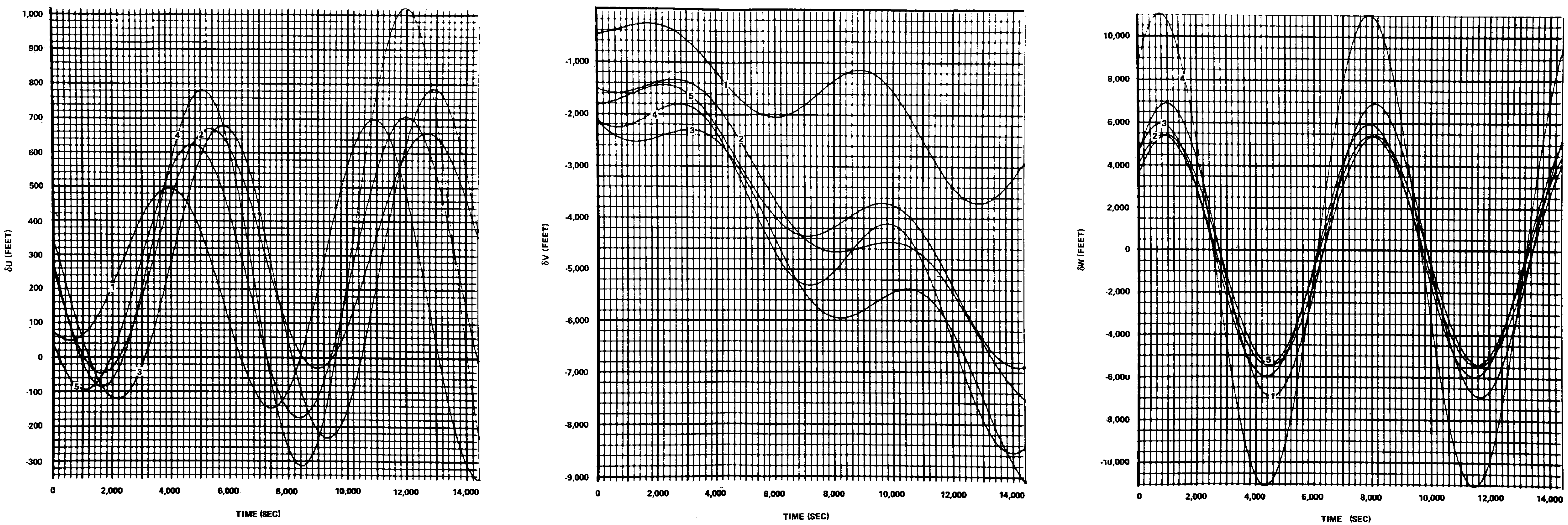

FIGURE 2a- TYPE II COMPARISONS (δU, δV, δW POSITIONS)

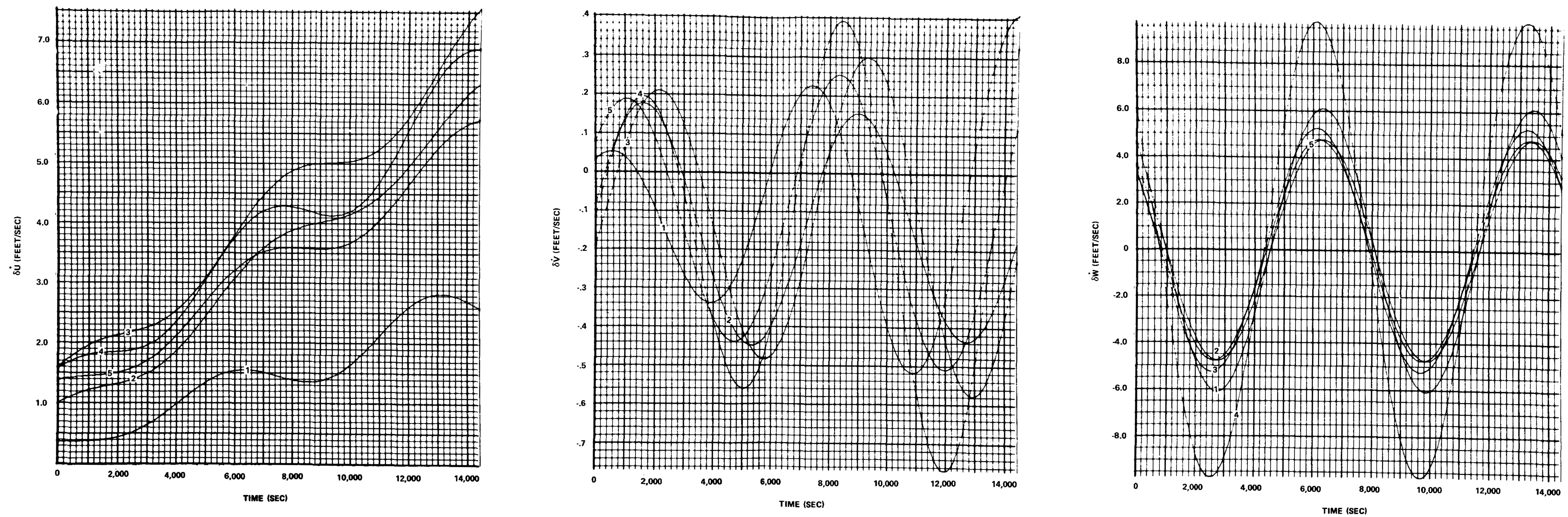

FIGURE 2b- TYPE II COMPARISONS ($\delta\dot{U}$, $\delta\dot{V}$, $\delta\dot{W}$ VELOCITIES)

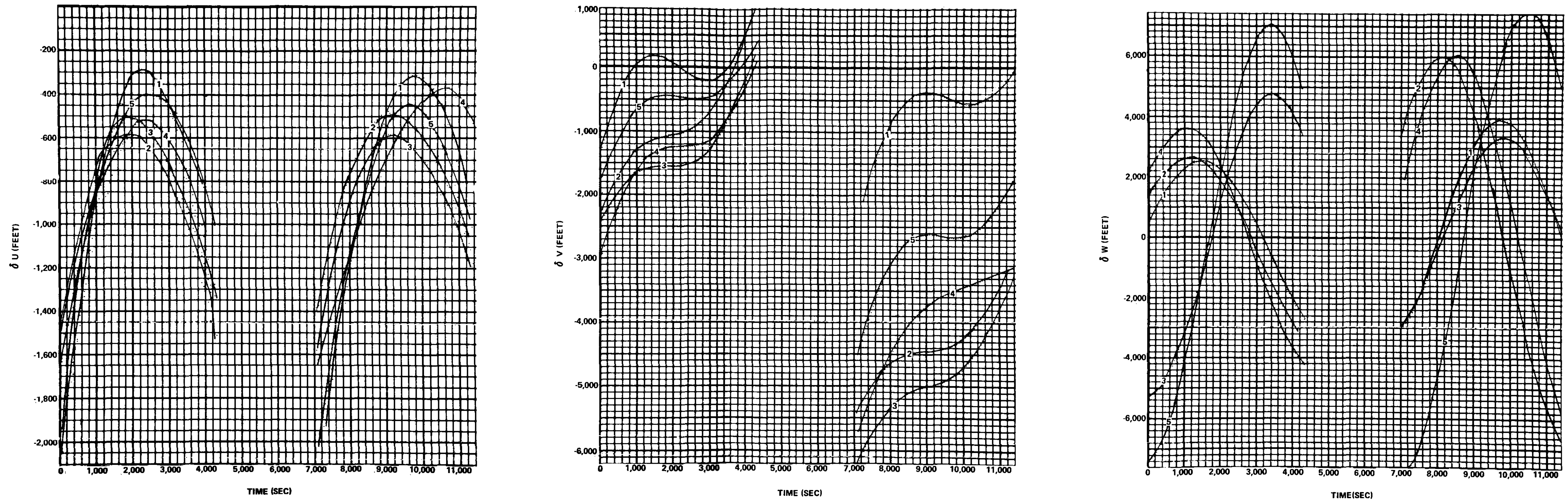

FIGURE 3a - R2 LOCAL SOLUTIONS VS. OLEP EXTRAPOLATED SOLUTIONS
(δU, δV, δW POSITION)

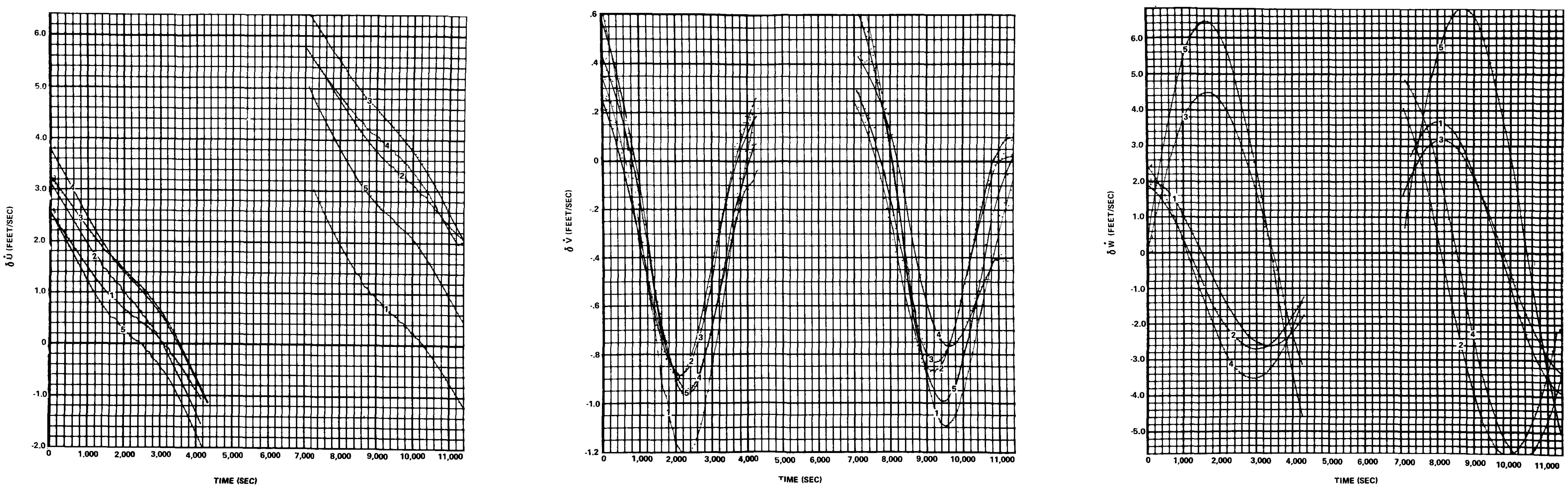

FIGURE 3b - R2 LOCAL SOLUTIONS VS. OLEP EXTRAPOLATED SOLUTIONS
($\delta\dot{U}$, $\delta\dot{V}$, $\delta\dot{W}$ VELOCTIES)

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